Industry standards for recognition of marginal wood defects

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Abstract

This study of 46 U.S. wood products companies that manufacture a variety of hardwood products found no consistently applied formal or standard definition of what constitutes a marginal defect. Analysis indicated homogeneous yet nonspecific rules are used. While there were wide variations in criteria, similar quantitative terms were used. Two distinct classes of defects emerged. One group, encompassing holes, knots, and checks, appears to be well defined, while the other, encompassing stain, mineral, color harmony, and incipient decay, is left to subjective evaluation. For example, hole identification appears to be based solely on diameter, knot identification on diameter and occurrence, and check identification on length and width. For the second group, defect elimination and cutting decisions appear to be based more on how obvious a defect may be in the end product rather than on explicitly defined sizes and colors. In some cases, the cost of the end product does not directly reflect the number or size of wood defects allowed, but rather the manufacturing steps involved and the relative mechanization in manufacturing the product. A computer vision system now under development can identify size, color, and pattern differences and locate the board edge, type of defect, and its location. However, the cost and functional speed of the system is directly related to the specific requirements of the user. It is essential that measures used by industry be translatable into parameters usable by the vision system. With such standardization, one vision system can be tailored to identify specific defects for various manufacturers based on the quality needs of their individual product lines. The objective of this effort was to quantify information on the maximum allowable defects by product and species. This is the first effort and points to the need for additional work before a complete vision system is built.

After primary breakdown of hardwood logs, the random-length/random-width lumber is usually dried in the conventional manner. After grading, the lumber is lightly surfaced on two sides and further processed into parts for furniture, dimension, or other manufactured wood products. However, many boards contain defects (i.e., knots, wane, stain, checks, etc.) that are not allowed in the clear pieces produced in the rough mill. Rough mill production is presently accomplished by humans operating crosscut and ripsaws. Frequently, the yield of usable parts is significantly diminished in this operation by human error, inattention, inadequate supervision, or poor equipment design. Studies indicate that humans are only about 68 percent accurate in their ability to perfectly recognize and locate such surface defects (4) in a plant environment.

In a proposed completely new process, the Automated Lumber Processing System (ALPS) (7), human operators need not locate defective areas on boards or be responsible for devising crosscut and rip strategies for cutting around them. In the ALPS process, the surfaces of the boards are scanned with a video camera and the image information is digitized. A computer then rapidly analyzes the data for tonal, textural, and color information and identifies the defects and their location. The image-derived defect data is then used to compute an optimum cutting strategy for each board to maximize yield for a given cutting bill (6).

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TABLE 1. – *Characteristics of the industry sample by product category and quality.*

Quality	Furniture	Furniture dimension	Kitchen cabinets	Millwork	Caskets	Other[a]
High	18 (49%)	6	8	--	2	--
Medium	14 (55%)	2	4	--	0	--
Medium low	--	1	1	--	1	--
Total companies	27	6	10	8	3	2
Glued panels	67%	17%	10%	0%	33%	0%

[a] This category included doors, door panels, door frames, flooring, novelties, and industrial products.

A laser cutting system, rather than conventional saws, is used to further maximize yield through the laser's ability to produce a very thin kerf and make "blind" cuts (7). The ALPS process has been determined to be economically feasible (3,5).

Optical imaging methods seem technically feasible, but current systems are not capable of detecting the variety and size of defects in appearance-sensitive operations. With existing systems, marginal flaws require manual suppression or enhancement for proper operation. The ALPS vision system is significantly more sophisticated and will be expected to not only detect a wide range of surface defects, but also classify them by type and size (i.e., checks, knots, decay, etc.). Thus, ALPS can potentially allow the manufacturer to define which defects or character marks may or may not appear in each piece of a cutting bill.

While feasibility studies have shown the image analysis system under development can accurately differentiate defects from clear wood and identify them (1,2), it is important to be able to further delineate between acceptable, sometimes acceptable, and unacceptable defects. This is a subjective matter related to the product and to the user's definition of a defect. To reduce computational time and program complexity, an early decision for wood characteristics or defects deemed acceptable, possibly acceptable, and unacceptable, is needed. While the number of sometimes acceptable and unacceptable defects may well be small, ALPS needs to be sufficiently flexible to meet the individual needs of a wide range of users.

Objective

To design an effective and cost efficient computer-based, defect-detection system, it is essential to understand and objectively define what various manufacturers regard as defects in their products. There is currently no published information or industry standard for acceptable, sometimes acceptable, and unacceptable defects. Informal discussions by the authors indicate a wide range of methods of communicating the company's standard to workers.

The objective of this study was to determine what, in industrial practice, constitutes a marginal defect and to what extent, if any, formal written or visual standards are used. A marginal defect was defined as the maximum allowable defect as defined by size and type. When no formal system was found, a system having specified size limitations for each type of defect was proposed to the manufacturer.

Method

A list of 46 diverse wood products manufacturers was selected from the American Furniture Manufacturers and National Dimension Manufacturers Associations directories. The companies selected were located in five geographic regions: North Carolina/Virginia [19]; Los Angeles, Calif. [8]; Tennessee, Arkansas, Mississippi, and Kentucky [7]; Wisconsin and Michigan [7]; and New Hampshire, New York, and Pennsylvania [5]. Defects, processing systems, and methods of communicating marginal or unacceptable defects for each industry group found in Table 1 were evaluated by direct observation through plant visits. Cooperation was requested prior to the visit. No statistical sampling method was used in selecting manufacturers, but an attempt was made to represent diverse product groups in many geographical areas. Table 1 summarizes the characteristics of the industry sample by product category and quality.

At each plant visit, and after observation and discussion of the defects allowed, an evaluation form summarizing the discussions was completed for later analysis. The form included the company and location (by code), the product produced, and the company's acceptance level of eight major defect types: knots, wane, holes, decay, color harmony, mineral streak and stain, checks, and splits. There were 171 entries made for all companies and species. Separate entries were created if the given manufacturer produced more than one product type and/or used more than one species of wood. Sixty percent of the products reported were furniture, 13 percent furniture dimension, 11 percent kitchen cabinets, 9 percent millwork, 6 percent caskets, and 1 percent other (doors, flooring, novelties, industrial products). Samples of the user defined defects were also collected and identified to aid in developing the computer vision system and to test the system response.

In Table 1, a double hyphen indicates no product quality assessment was reported. Total companies represent the number of companies manufacturing a given product. However, 6 of the 46 companies sampled manufactured multiple products – defined as those in a different product category or within the same category but of different quality. Thus, if the total is less than the sum of the product category, then the total includes multi-product companies. The parenthetical percentages adjacent to the number of high and low quality furniture companies represent the average amount of solid wood used for glued-up panels. Meaningful averages of glued panels for the other product categories are not tabulated because of the low number of companies reporting use of glued-up panels. The final line of Table 1 shows what percentage of companies within a product category uses glued-up panels. For example, 67 percent of the furniture companies reported using glued panels. The percentage of glued panels was calculated because the ALPS system is also investigating direct use of the laser charred surface for gluing panels.

Discussion of results

The results of this industrial survey are tabulated by product category, defect type, and species in Tables 2 through 6. All geographic regions sampled are represented in the tabulations. A precise mathematical analysis of the results is not possible but it is evident that a very wide range of definitions for a marginal defect are employed in industry, depending on species and end product. One interviewed individual stated, "If you can see it, it's a defect." Yet a previous study by the authors (4) indicated that rough mill operators work at only about 68 percent accuracy in the task of identifying and locating defects for exclusion. Some rough mill operators were even found to have substandard vision.

It can generally be stated that higher quality products (furniture and furniture dimension) require more clear surface area with smaller and fewer defects. Since these products constituted 84 percent of the sample, which is close to the industry average as a whole, the definitions obtained with respect to both size and presence must be carefully considered in the design of the ALPS vision detection system. One unexpected qualification must be made. The kitchen cabinet industry is generally considered a lower end user, yet the survey indicated the need for an almost perfect surface. Even high quality furniture manufacturers appear to be more generous in their acceptance of defects. The reason given is that furniture manufacturers expect and do repair marginal defects during finishing, while kitchen cabinet manufacturers operate more highly automated finishing systems that do not facilitate repair of blemishes. The reasoning for including some de-

TABLE 2. — *Summary of furniture and dimension defect classification by species.*

Species	No. of companies reporting	Maximum size of defect allowed							
		Knots	Wane	Holes	Decay	Color harmony	Mineral streak and stain	Checks	Splits
		(in.)[a]		(in.)[a]				(in.)[b]	
Red oak	31	1/4 to 1/32	None	1/8 to 1/64	None[c]	None to some	None to some	1/32 by 1	None
Hard maple	16	1/8 to 1/32	None	1/16 to 1/64	None[c]	None to some	Some	1/16 by 1/8	None
White oak	10	1/2 to 1/16	None	1/16 to 1/32	None to some	None to some	Some	1/16 by 1/4	None
Soft maple	10	1/2 to 1/16	None	1/8 to 1/32	None to some	None to some	None to some	1/16 by 1/4	None
White ash	9	1/4 to 1/16	None to some	1/8 to 1/32	None[c]	None to some	None to some	None to some	None to some
Honduran mahogany	9	1/4	None	1/16 to 1/64	None	None to some	None to some	None	None
Yellow-poplar	9	1/8	None	1/4 to 1/16	None[c]	None to some	None to some	None to some	None
Hickory/pecan	6	1/4 to 1/16	None	1/8 to 1/16	None[c]	None to some	None to some	1/32 by 1/4	None
White pine	6	1-1/2	None	1/8 to 1/16	None to some	None	None to some	1/32 by 1/4	None
Black cherry	5	1/4 to 1/16	None	1/16 to 1/64	None	None to some	Some	None to some	None

[a] Inches in diameter.
[b] Inches of width by inches of length.
[c] In these cases, companies did allow slight discoloration due to early decay.

TABLE 3. — *Summary of kitchen cabinet defect classification by species.*

Species	No. of companies reporting	Maximum size of defect allowed							
		Knots	Wane	Holes	Decay	Color harmony	Mineral streak and stain	Checks	Splits
				(in.)[a]				(in.)[b]	
Red oak	9		None	1/32 to none	None[c]	None to some	None to some	None to 1/32 by 1	None
Beech	2		None	None to 1/32	None	None to some	Some	None	None
Sycamore	2		None	None to 1/32	None	None to some	None to some	None	None
White oak	1		None	None	None	None	Some	None	None
Hard maple	1		None	None	None	None	Some	None	None
Black cherry	1		None	1/64	None	None	None	None	None

[a] Inches in diameter.
[b] Inches of width by inches of length.
[c] In these cases, companies did allow slight discoloration due to early decay.

TABLE 4. — *Summary of millwork defect classification by species.*

Species	No. of companies reporting	Maximum size of defect allowed							
		Knots	Wane	Holes	Decay	Color harmony	Mineral streak and stain	Checks	Splits
Red oak	3		None		None to some	None to some	None to some		None
White oak	1		None		Some	Some	Some		None
Yellow-poplar	1		None		None	None	Some		None
White ash	1		None		None	None	Some		None
White pine	1		None		None	None	1/4		None
Red alder	1		None		Some	None	None		None
Banak	1		None		None	None	None		None

[a] Inches in diameter.
[b] Inches of width by inches of length.

TABLE 5. — *Summary of casket defect classification by species.*

Species	No. of companies reporting	Maximum size of defect allowed							
		Knots	Wane	Holes	Decay	Color harmony	Mineral streak and stain	Checks	Splits
		(in.)[a]		(in.)[a]				(in.)[b]	(in.)[b]
Red oak	2	1/2 to 1/8	None	None to 1/32	None	None	Some	1/32 by 1	None to 1/32 by 1
Hard maple	1	1/8	None	None	None	None	Mineral OK	1/32 by 1/2	None
Black cherry	2	1/2 to 1/8	None	None to 1/32	None	None	Some	1/32 by 1	None to 1/32 by 1
Yellow-poplar	1	Some	None	1/4	None	Some	Some	1/8	None
Aspen/cottonwood	2	1/2 to 1/4	None	None to 1/32	None	None	Some	1/32 by 1	None to 1/32 by 1
White pine	1	Some	None	None	None	None	Some	1/32 by 1/2	None
Walnut	1	None	None	None	None	Some	Some	1/32 by 1/2	None

[a] Inches in diameter.
[b] Inches of width by inches of length.

TABLE 6. — *Summary of other product defect classification* by species

Species	No. of companies reporting	Maximum size of defect allowed							
		Knots	Wane	Holes	Decay	Color harmony	Mineral streak and stain	Checks	Splits
		(in.)[a]		(in.)[a]				(in.)[b]	
Doors, door panels, door frames, and flooring									
Red oak	5	None to 1/8	None	None to 1/4	None to some	None to some	None to some	None to 1/2 by 1/64	None
Hard maple	1	1/8	None	None	Some	Some	Mineral OK	1/2 by 1/64	None
Novelties									
Soft maple		1/16	None	None	None	Some	Some	None	No
Industrial products									
Soft maple	1	1/32	None	1/32	None	None	Some	None	None

[a] Inches in diameter.
[b] Inches of width by inches of length.

fects and repairing them is that such repair steps tend to keep yield higher and material costs lower. The cost associated with repairs varies, as some defects are more easily repaired than others. For example, a given product line may have two or more shades of finishes. Material containing stain or mineral streak could simply be placed in a dark finish group, thus masking the defect at no additional cost. However, holes are difficult and costly to repair and must be limited in size. Defects such as splits are impossible to repair, may cause a failure, and are objectionable to all the industry.

If the material must be absolutely defect or blemish free, yield of parts will be diminished and material cost will substantially increase. For high cost species such as walnut, cherry, or oak, the material cost increase is significant. For lower value species such as gum or cottonwood, the cost escalation associated with yield reduction will be less dramatic.

In this survey, no manufacturer indicated that they had studied consumer sensitivity to defects. Yet all manufacturers tried to establish standards that reflected what they thought the consumer wanted and expected. Some marketing techniques have affected consumer acceptance of some defects. Examples include knotty pine furniture, which allows sound knots, and "distressing" in antique furniture reproductions, which can mask certain defects.

The foundation for developing standard marginal defect descriptions rests upon achieving an economic balance among material cost, defect repair, and acceptable product standards. Most companies do not consciously calculate this cost, but many would benefit from such an exercise. Thought should also be given within the industry to categorizing defects by repair cost and the quality standard required by consumers.

It was disappointing to the researchers that more companies did not have formal methods of specifying what constitutes a defect in their product. Only 3 companies of the 46 observed had any written system. Most depended on subjective verbal information relayed to the responsible production workers. A few companies had samples of acceptable pieces as a standard for employees to observe and compare.

The results of this study address the need for an objective defect classification system to facilitate the development of an industrially useful automated computer-vision, defect-detection system, i.e., a homogeneous set of rules that can be used to describe most defects in many products. Of the product categories sampled, no manufacturer allows splits, wane, or decay. Thus, any vision system developed must be capable of consistently and accurately detecting these defects. Only holes of very small size are allowed and knots are limited by size. Color, grain pattern, stain, and burl are more difficult to define, and therefore, are more difficult to analyze as defects. These defect types may be defined more by appearance or emotion rather than size or number. In these subjective areas it will be even more important to customize the defect detection system to each individual wood products manufacturer. The information contained here may assist additional manufacturers to more carefully consider what truly constitutes a defect in their products. Progress will only be made if additional companies are able to accurately define marginal defects and provide rules describing them. Given such information, there is little doubt that a computer-vision system can be developed to automate defect detection in the wood products industry as has occurred in other industries.

Summary and conclusions

Presently, conventional crosscut and ripsaw equipment is operated by humans to produce defect-free parts from hardwood lumber. The resulting yield of usable parts is frequently below optimum because of human error, inattention, and inadequate training or supervision. A computer-vision system that can accurately differentiate defects from clear wood and identify them by type is currently under development. The vision system is coupled with a yield optimization program and with a laser that cuts the desired parts from the lumber. The cost of applying the vision system, in terms of material, yield, and repairs, will increase as increased definition is demanded. Therefore, the degree of defect definition should be related to the end use of the part within the product, as some defects may be hidden from view.

This study found that the definitions of marginal defects vary widely among producers of competing products, due to differences in product quality. No consistently applied formal defect standards within the industry were found. Analysis of the data collected from manufacturers of various products indicates there are two distinct classes of marginal defects. In one group, actual defects were measured and classified using similar quantitative and qualitative terms across a broad range of products. For example, hole identification appears to be based solely on diameter, knot identification on diameter and soundness, and check identification on length and width. No manufacturers accepted wane or splits. In the second group, which contains defects such as decay, color, and stain, the defects were identified using qualitative terminology. However, it is important to note that many company officials surveyed incorrectly described these marginal defects in terms of exact measurements. This suggests that some wood processing decisions are based more on how obvious a defect may be in the end product than on explicitly defined sizes and colors. Further work needs to be done in developing and testing a defect definition system acceptable to the industry. This study may provide the basis for initiating wood product defect definitions.

The ALPS computer-vision system now under development can differentiate size, color, and pattern differences among background, clear wood, and defects, and hence, locate the edges of boards, the type of defect, and its location. However, the cost and functional speed of such a system is directly related to how precisely the requirements of users can be defined, which can vary considerably, as shown in this survey. It is essential that the qualitative and quantitative measures used by industry be translatable into parameters usable by the vision system. Given standardized parameters, a versatile vision system that can be individually tailored to identify specific defects to meet the quality needs of any manufacturer can be designed.

It is hoped this study will encourage more companies to accurately describe and define defects. If more thought is given to this subject, the ultimate development of a computer-vision, defect-detection system will be accelerated.

Literature cited

1. Conners, R.W., C.W. McMillin, K. Lin, and R.W. Vasquez-Espinosa. 1983. Identifying and locating surface defects in wood: part of an automated lumber processing system. IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol. PAMI-5, No. 6, Nov.
2. ________, C.T. Ng, T. Cho, and C. McMillin. Computer vision system for locating and identifying defects in hardwood lumber. Application of Artificial Intelligence VII. Sponsored by the Inter. Society of Man and Cybernetics Society of IEEE.
3. Huber, H.A., C.W. McMillin, and A. Rasher. 1982. Economics of cutting wood parts with a laser under optical image analyzer control. Forest Prod. J. 32(3):16-21.
4. ________, ________, and J.P. McKinney. 1985. Lumber defect detection abilities of furniture rough mill employees. Forest Prod. J. 35(11/12):16-21.
5. ________, S. Ruddell, K. Mukherjee, and C. McMillin. 1989. Economics of cutting dimension parts with an automated system. Forest Prod. J. 39(5):46-50.
6. Klinkhachorn, P., J.P. Franklin, C.W. McMillin, and H.A. Huber. 1989. ALPS yield optimization cutting program. Forest Prod. J. 39(3):53-56.
7. McMillin, C.W., R.W. Conners, and H.A. Huber. 1984. ALPS — a potential new automated lumber processing system. Forest Prod. J. 34(1):13-20.